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INVESTIGATION OF PROPELLANT AND HIGH EXPLOSIVE
DISPOSAL BY CONFINED SPACE SHOTS-II

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Confined space disposal is at a great disadvantage when other methods of disposal exist, such as wet-air oxidation or controlled incineration, when munitions may be uncased or when continuous operations are feasible. Primary disadvantages are the danger in transporting old, sensitive devices, initial investment required, emplacement costs and dangers in bringing sensitive ordnance material within sympathetic detonation distances before the shot is fired. Also, in general, reclamation of the product gases and conversion to useful products is not feasible.

INVESTIGATION OF PROPELLANT AND HIGH EXPLOSIVE DISPOSAL BY CONFINED SPACE SHOTS - II

ABSTRACT

The disposal in a confined space of both military secondary high explosives and homogeneous propellants has been studied. Research on an engineering basis has been accomplished as to the feasibility of disposing of outdated military munitions in a confined space, and also as to the practicality of explosion product gas recovery for reuse in explosives synthesis.

Disposal in a confined space is advantageous when one wishes to dispose of large batch configurations of explosive devices which are dangerous to uncase, where another method does not exist, and from the standpoint of environmental impact. For example, a twenty-five ton high explosive shot may be easily contained within a cavity of about sixty-eight feet in diameter, with great attenuation of the shock wave and complete containment of the product gases.

Confined space disposal is at a great disadvantage when other methods of disposal exist, such as wet-air oxidation or controlled incineration, when munitions may be uncased or when continuous operations are feasible. Primary disadvantages are the danger in transporting old, sensitive devices, initial investment required, emplacement costs and dangers in bringing sensitive ordnance material within sympathetic detonation distances before the shot is fired. Also, in general, reclamation of the product gases and conversion to useful products is not feasible.

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EXPLOSIVE DISPOSAL IN CONFINED SPACES - II

Introduction:

Recent public and governmental concern over polluting materials and their discharge into the environment has caused the military to take a closer look at its methods of explosives disposal.

Recent methods of disposal have included open burning, incineration, open detonation, biochemical degradation, partial chemical recovery and deep ocean dumping. Each of these methods is in some way unsatisfactory to the environmentalist on the basis of trade-offs that must be made between safety, cost, and environmental impact.

For example, the open burning of 3.8 tons of trinitrotoluene produces 625 pounds of soot¹ alone, in addition to the toxic gases -- such as carbon monoxide and the oxides of nitrogen -- as well as increasing the thermal loading of the atmosphere.¹

Another example concerns the chemical recovery of minol² by steam washout, which has had the effect of raising the amount of nitrates and nitrites in nearby stream and river waters, and thereby causing eutrophication and , in general, upsetting the ecological balance of the biosphere.

Another similar situation existed in deep ocean dumping in which marine life was damaged by the toxic chemicals in the explosive, or its explosion products.³

In response to the problems typified by the above examples, research is now in progress around the country in both military and civilian laboratories to find acceptable ways to dispose of waste materials such as outdated explosives and explosive devices without polluting the atmosphere.

We have chosen to examine the disposal of explosives by detonation and/or deflagration in a closed space.

The idea of detonating explosives in a large, air-filled container is not new. In December 1959 through March 1960, the Atomic Energy Commission ran a series of chemical explosions, called "Project Cowboy", ranging from 20 to 2000 pounds in both tamped holes and in 12 and 36 foot diameter spheres, to study seismic phenomena and shock decoupling,⁴ also, the A.E.C., in "Project Sterling", studied ground motion and containment of a 0.35-kT yield nuclear device emplaced in the center of a cavity created by a previous nuclear explosion in a halite (salt) medium. This cavity was about 2700 feet deep, approximately spherical and with a diameter of 112 feet.^{5,17}

The concept of disposing of large batch quantities of waste or outdated explosives in a confined space originated with Professor J.E. Sinclair, at the Naval Postgraduate School. Parts of this project were accomplished by two thesis students -- Young and Visted.^{6,7}

Their ideas envisioned large batch quantities of explosives being destroyed in a large underground chamber, with the resulting polluting products being vented to processing equipment; to the atmosphere during meteorologically acceptable conditions; or kept contained for long periods of time.

Also proposed, was the idea of detonating repeated batch quantities in the same chamber without venting each time, thereby concentrating the gases given off in the explosion process. Then, after an appropriate number of shots, processing the gases to reclaim useful products, or perhaps expanding them through a generator to produce electricity.

What are some of the explosives available for disposal? The quantities of explosives that are excess or outdated are not small. They include many old mines and casings, as well as certain types of bombs and cartridges, many of these items contain large quantities of TNT. Others contain HBX, Tetryl, Ammonium Nitrate, White Phosphorous, flash powder, or smokeless powder. Several of these contain azides as initiators which may have combined with casing metals to form such things as copper azide, which is quite sensitive. In addition to the H.E. and propellants involved, there is a tremendous amount of metal in these devices. For example, of about 68,000 gross tons of AEDA material available for disposal, over 68% is hardware. Of the remaining 30%, 15% is H.E., and 15% is smokeless powder.⁸

Knowing some of the basic military secondary high explosives and homogeneous propellants used in these older devices, Young and Visted set out to make a laboratory model of a confined space disposal unit from which they could (1) identify the products of the explosion, (2) determine the variation in concentration of the major components upon successive shots in the chamber, and (3) measure the static pressures in the chamber after each shot sequence.

Experimental:

We have constructed a stainless steel cylinder with a capacity of 19.57 L with an airlock provision for loading consecutive samples of explosives into the chamber without changing the product concentration or the pressure by more than 0.25% per loading.⁷

Loading was accomplished by placing a blasting cap and a paper cartridge containing the explosive of interest into the cylinder through the airlock and firing it remotely through the electrical fixture passing through the center of the airlock shaft.

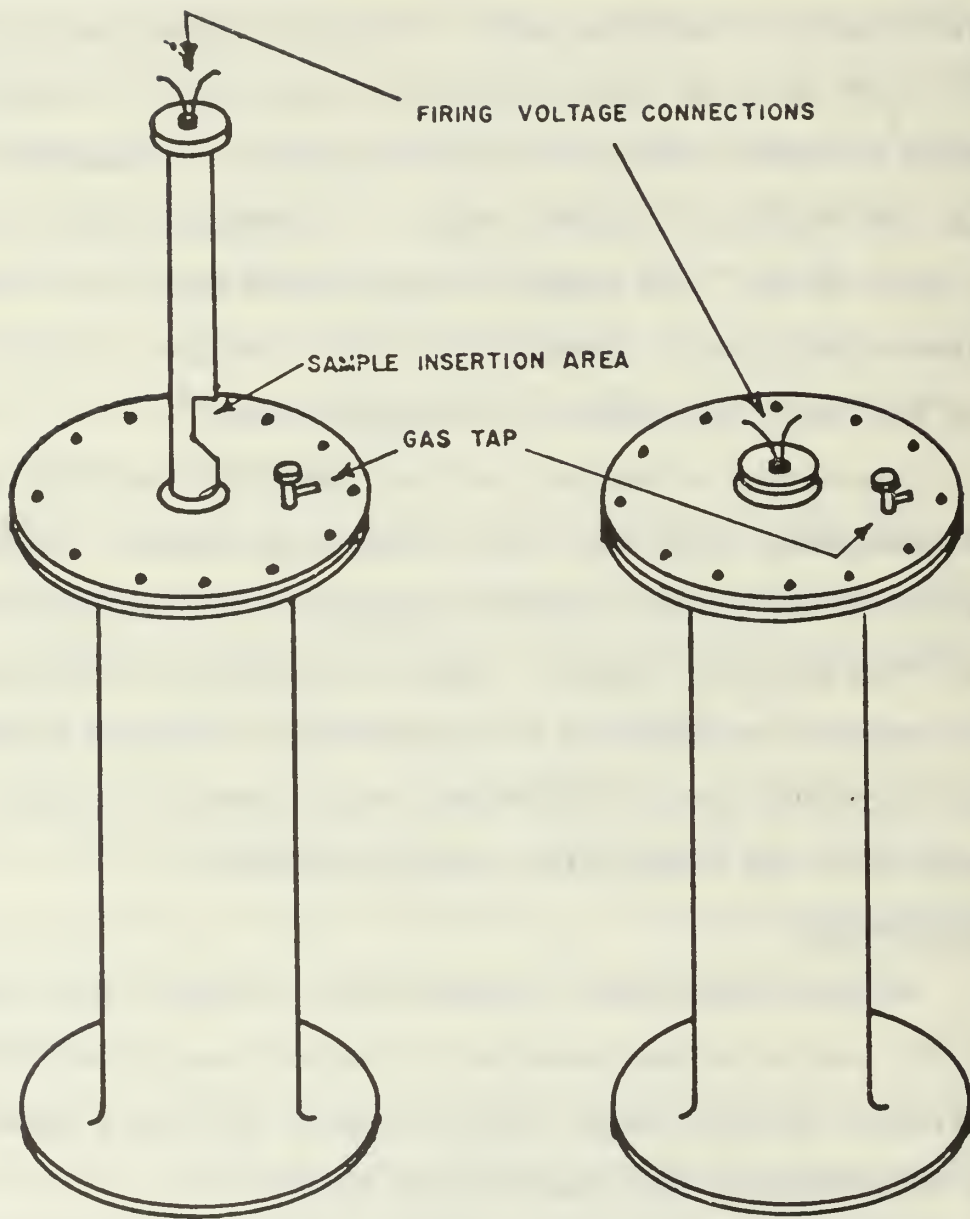


Figure 1: Loading and Firing Positions

FIGURE 2: Detail of Firing Assembly

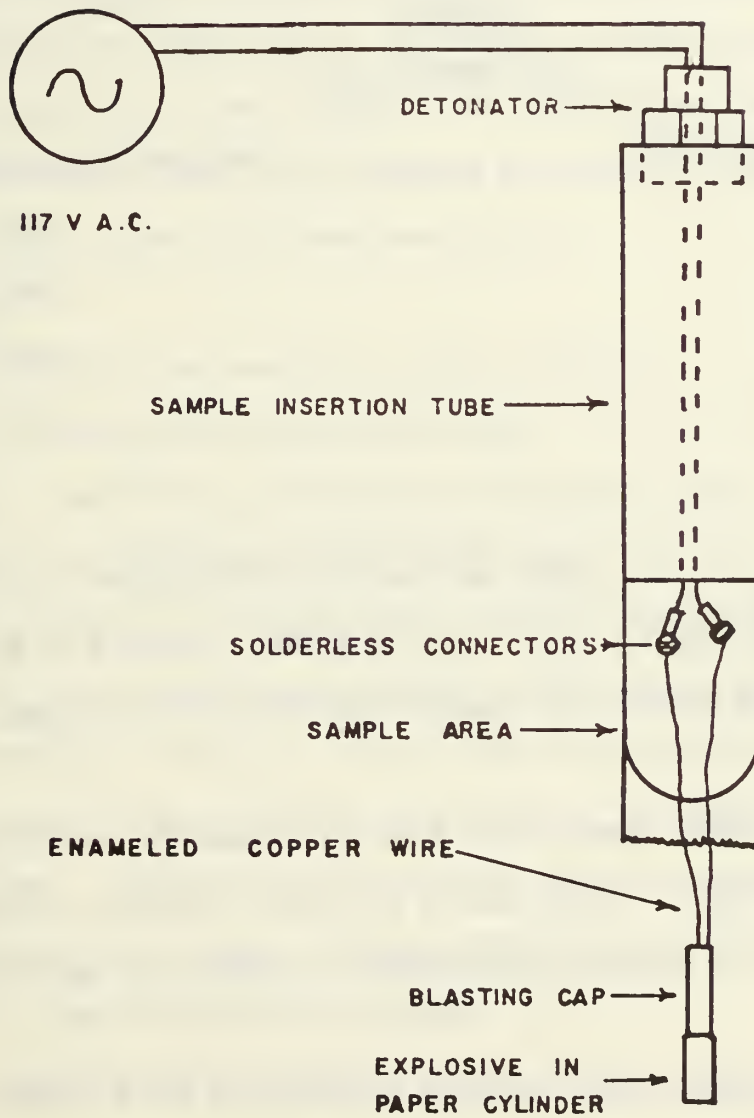


Figure 1 shows the sample chamber.

Figure 2 shows the electrical hook-up through the airlock device.

Test samples were some major military secondary high explosives and some homogeneous solid propellants, as shown in Figure 3.

FIGURE 3

TEST SAMPLES USED

SECONDARY HIGH EXPLOSIVES	HOMOGENEOUS SOLID PROPELLANTS
C-4	5066
TNT	2400
HMX	4198
RDX	4227
PETN	

In a typical run, the sample was loaded into the paper cartridge and attached to the blasting cap. This unit then connected to the wires of the firing circuit and lowered into the cylinder through the airlock.

The shot was fired remotely and time was allowed for sufficient mixing of product gases. Three samples were then withdrawn through the sample valve into evacuated containers for analysis by gas chromatography.

A Fisher gas partitioner, modified to include a third column freezing trap, was used for the gas analysis. Gases studied were oxygen, carbon monoxide, carbon dioxide, and nitrogen-nitrogen oxides. Hydrogen and methane were also attempted but were not observed in the sensitivity range of the chromatograph.

Following the withdrawal of the samples, another charge was placed in the chamber through the airlock and the entire process repeated until many grams of explosive had been used.

After the final shot of a series and withdrawal of the three samples, the static pressure was measured, using a pressure gauge attached to the sample valve. No attempt was made to control the wall temperature of the cylinder or to decouple the shock from the cylinder walls. Also, pure compounds were used for the explosive test samples rather than cased ammunition.

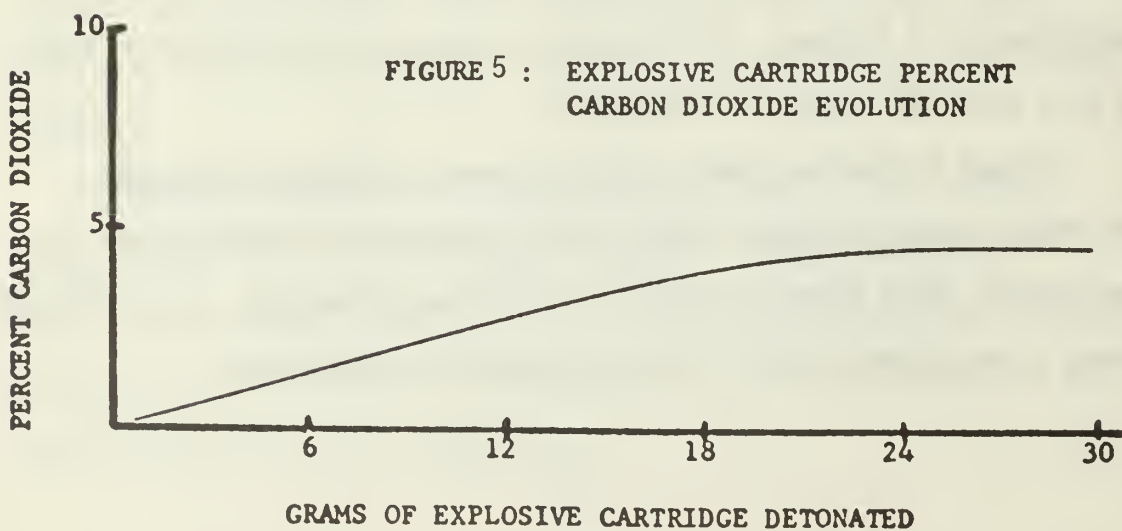
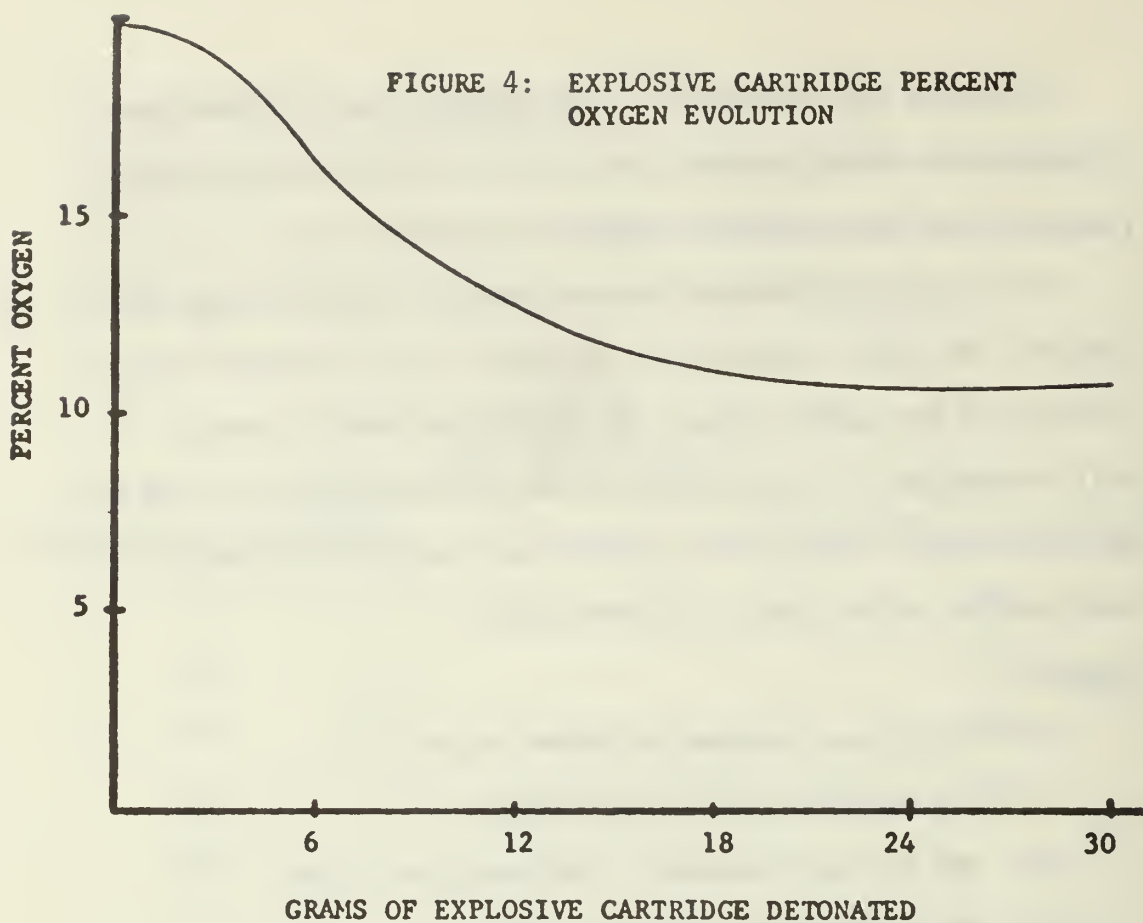
Results:

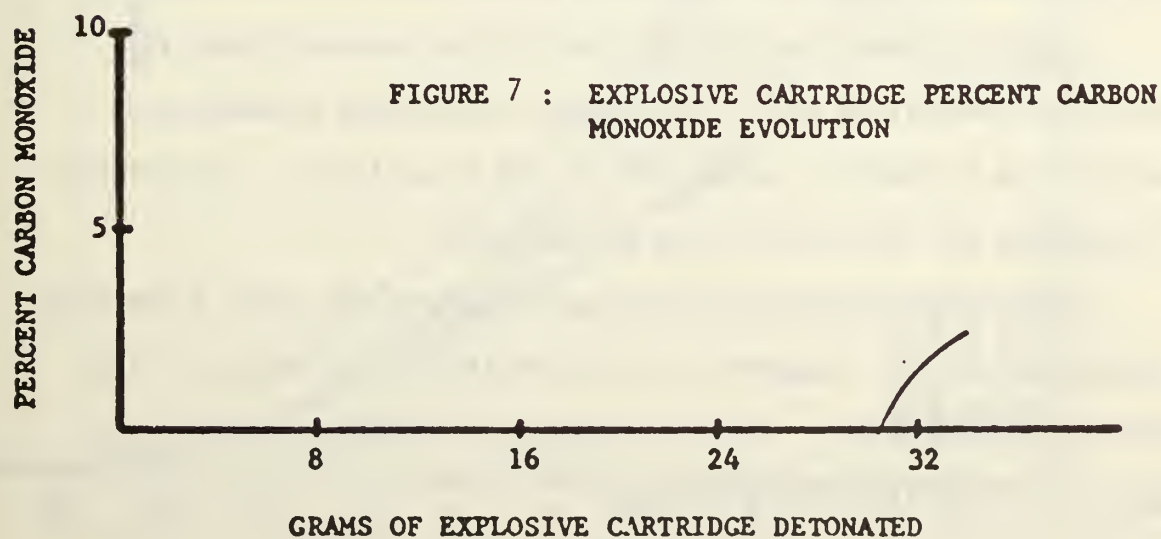
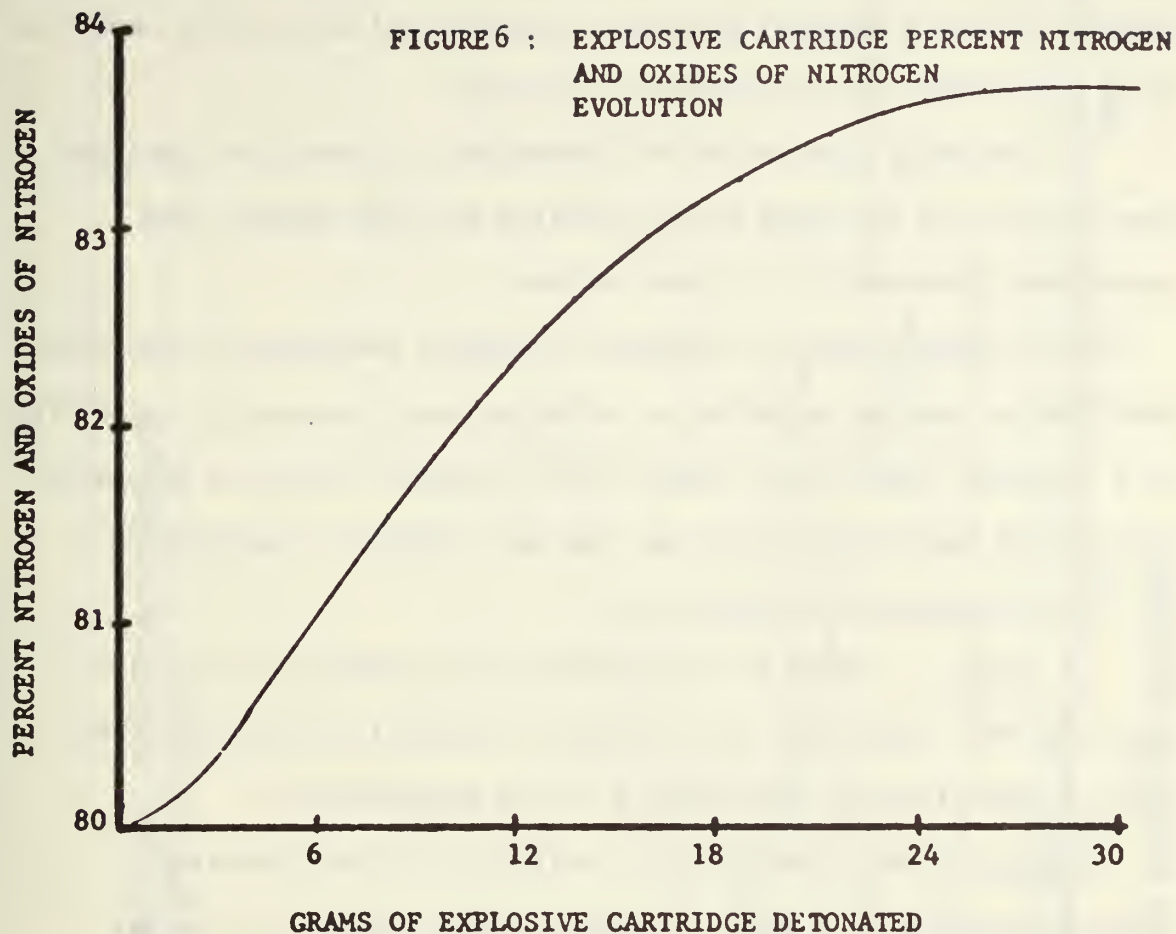
The results are examined in three groups ---

- (1) The explosive cartridge itself,
- (2) the military secondary high explosives, and
- (3) the homogeneous solid propellants.

The explosive cartridge was a standard aluminum shell electric blasting cap containing approximately .315 grams of pentaerythritoltetra-nitrate(PETN) as the main initiator and approximately 0.05 grams of heat sensitive lead styphnate as a primer. The paper cartridge weighed 0.55 grams. The blasting cap and paper shell combination weighed approximately 3.3 grams. An eight shot sequence was fired for a total of 30.1 grams of explosive cartridge.

Changes in the gas composition are seen in Figures 4 through 7. The major gaseous products stabilized in percentage concentration, in the area of 18-22 grams of explosive cartridge detonated. A significant point is the almost total absence of any carbon monoxide.





The growth of the nitrogen and oxides of nitrogen percentage concentration was expected because of the nitrocellulose, PETN, and lead azide ingredients of the explosive cartridge.

The secondary high explosives tested which covered the spectrum from oxygen rich to oxygen poor, exhibited the same general type percentage concentration of gases evolved.

From Figure 8, one can see that the oxygen percentage concentration exhibited a negative evolution as the oxygen was consumed, but stabilized at a constant level in the range of 10-12 grams of explosive detonated. The band of stabilization for the five test explosives varied from 3 to 6 percent oxygen concentration.

In Figure 9 carbon dioxide concentration exhibited a positive evolution that stabilized at 8-10 grams of explosive detonated. The band of stabilization varied from 9 to 15% concentration.

Figure 10 shows the positive evolution of carbon monoxide appearing after 5 to 7 grams of explosive were detonated. The gas concentration stabilized at 18 to 20 grams of explosive detonated and maintained a stability range of 6 to 15 percent concentration.

Figure 11 shows the nitrogen and nitrogen oxides' negative evolution stabilizing at 18 to 20 grams of explosive detonated and maintaining a stability range of 69 to 75% concentration. No methane or hydrogen was found during the gas analysis.

Steady-state chamber pressures were measured for some of the high explosives and were compared to the theoretical calculations by the Sinclair-Sewell method. Actual steady-state chamber pressures ran about 5 percent less than predicted.

FIGURE 8 : SECONDARY HIGH EXPLOSIVE PERCENT
OXYGEN EVOLUTION

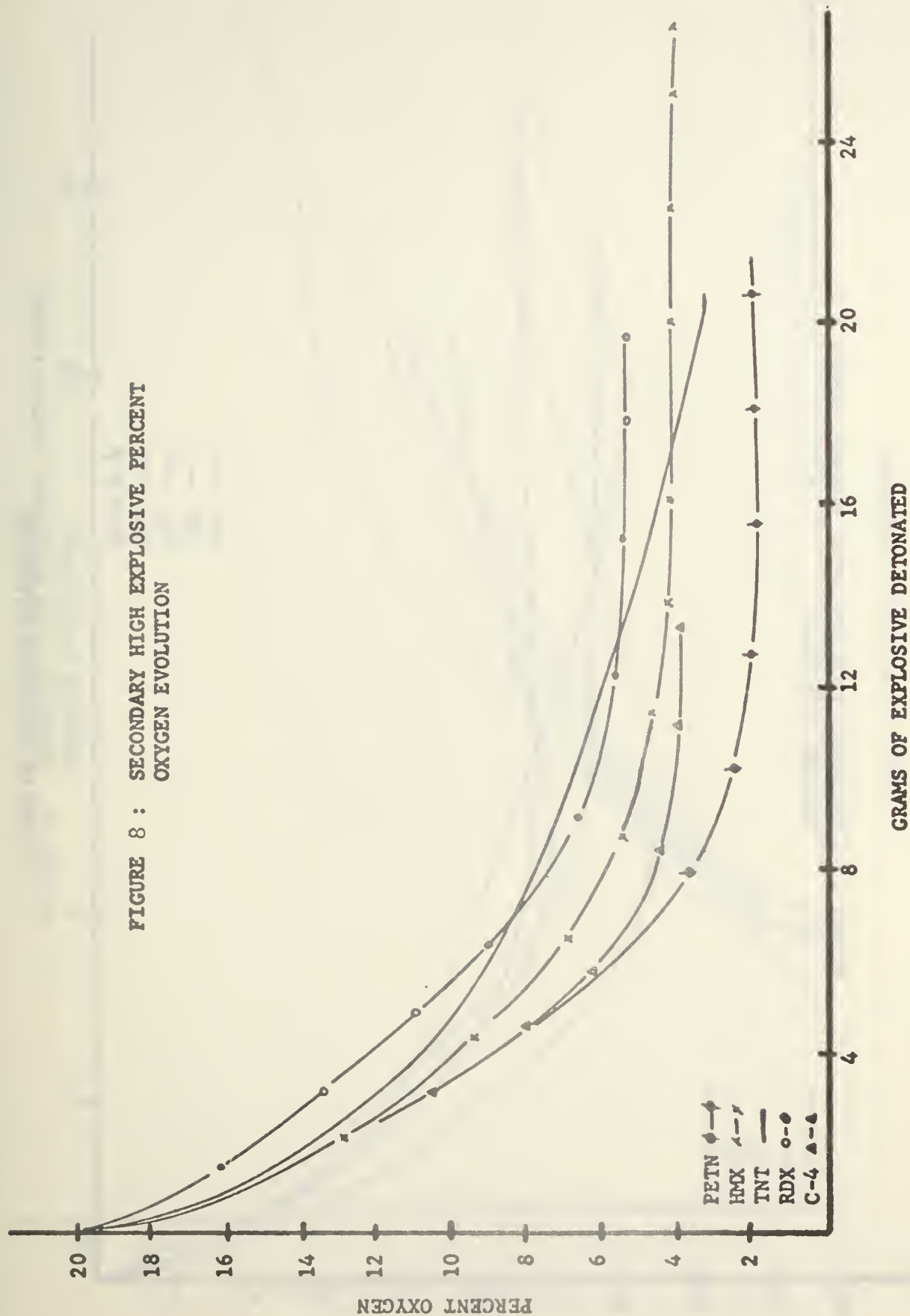


FIGURE 9.: SECONDARY HIGH EXPLOSIVE PERCENT CARBON
DIOXIDE EVOLUTION

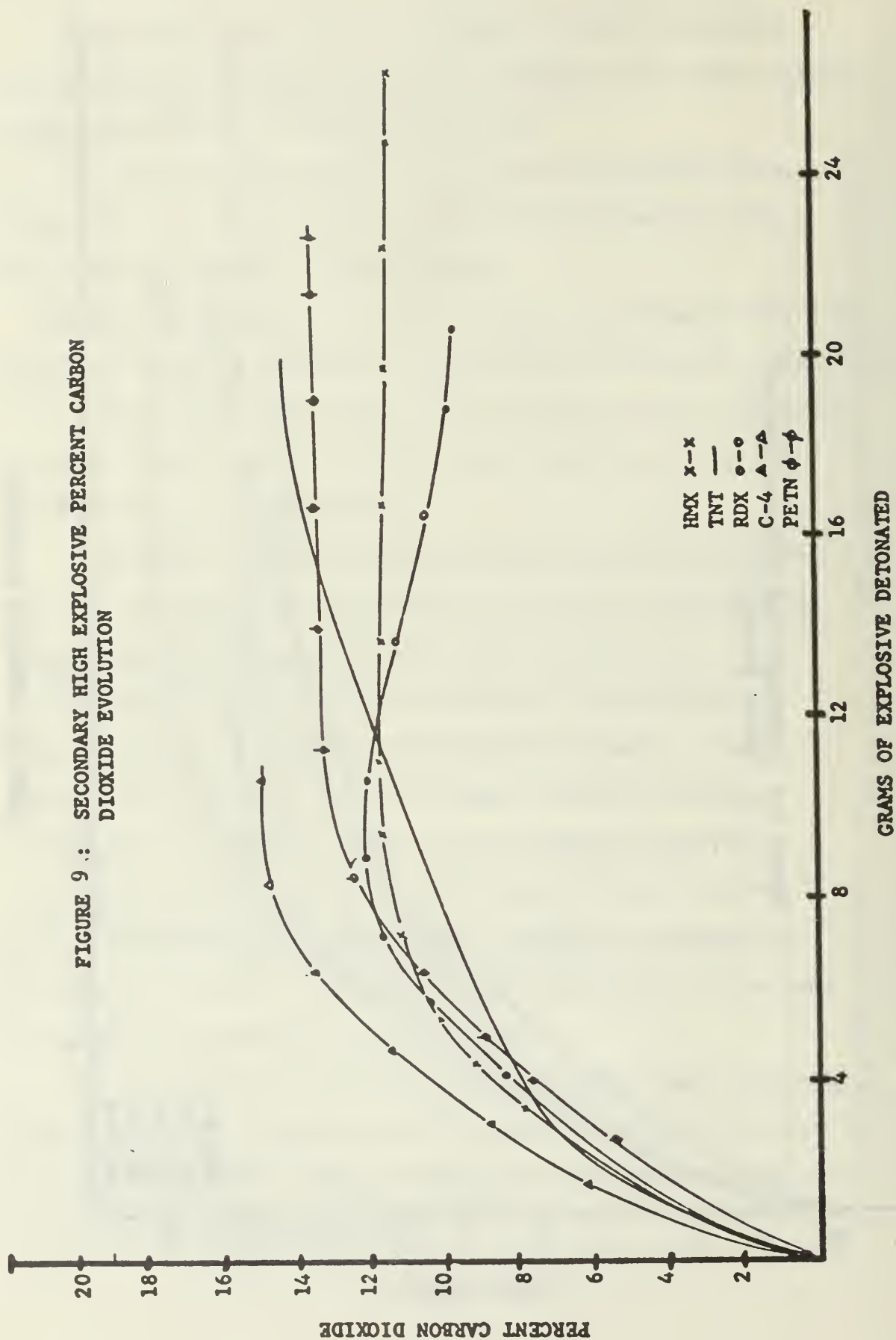


FIGURE 10: SECONDARY HIGH EXPLOSIVE PERCENT CARBON MONOXIDE EVOLUTION

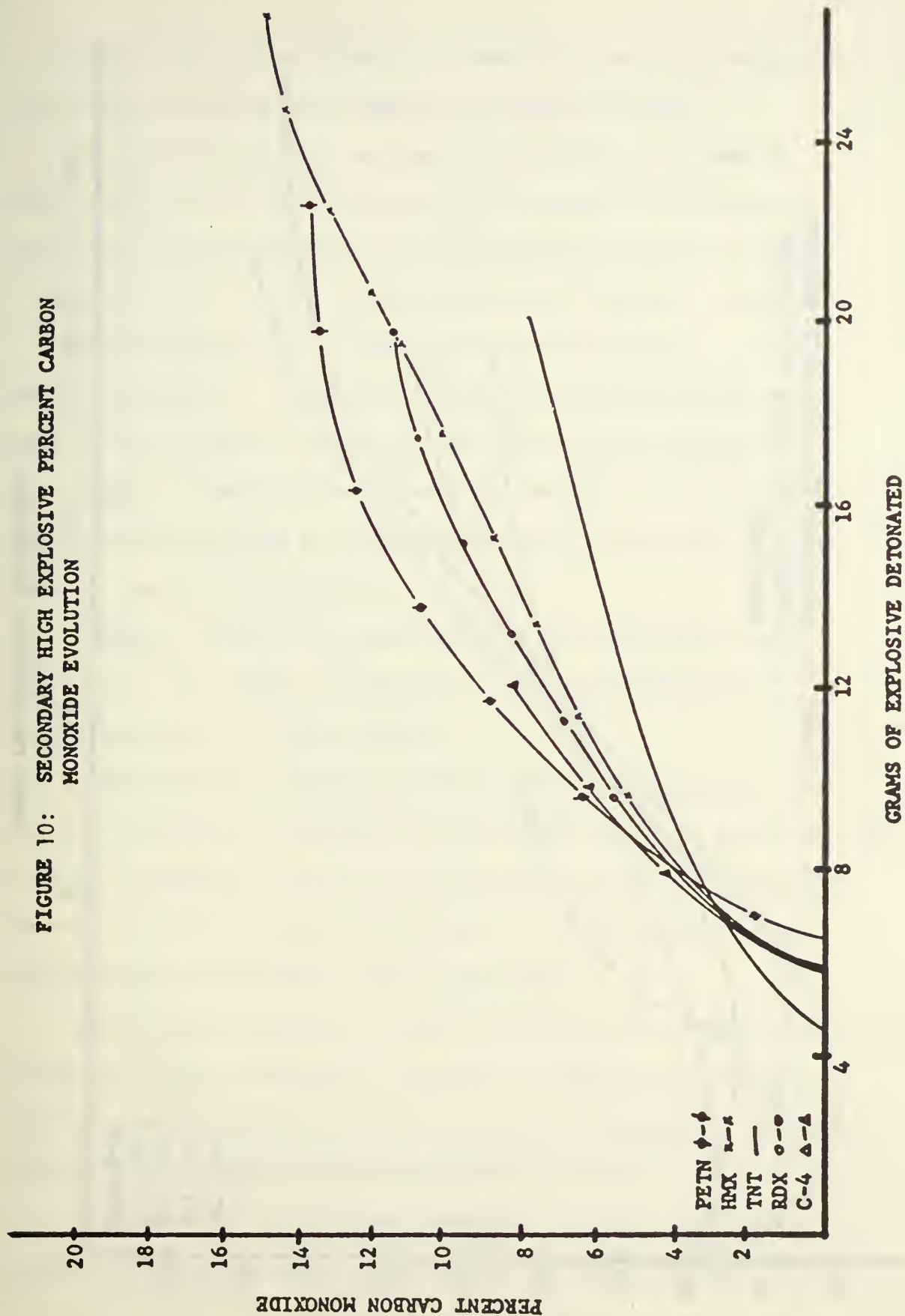
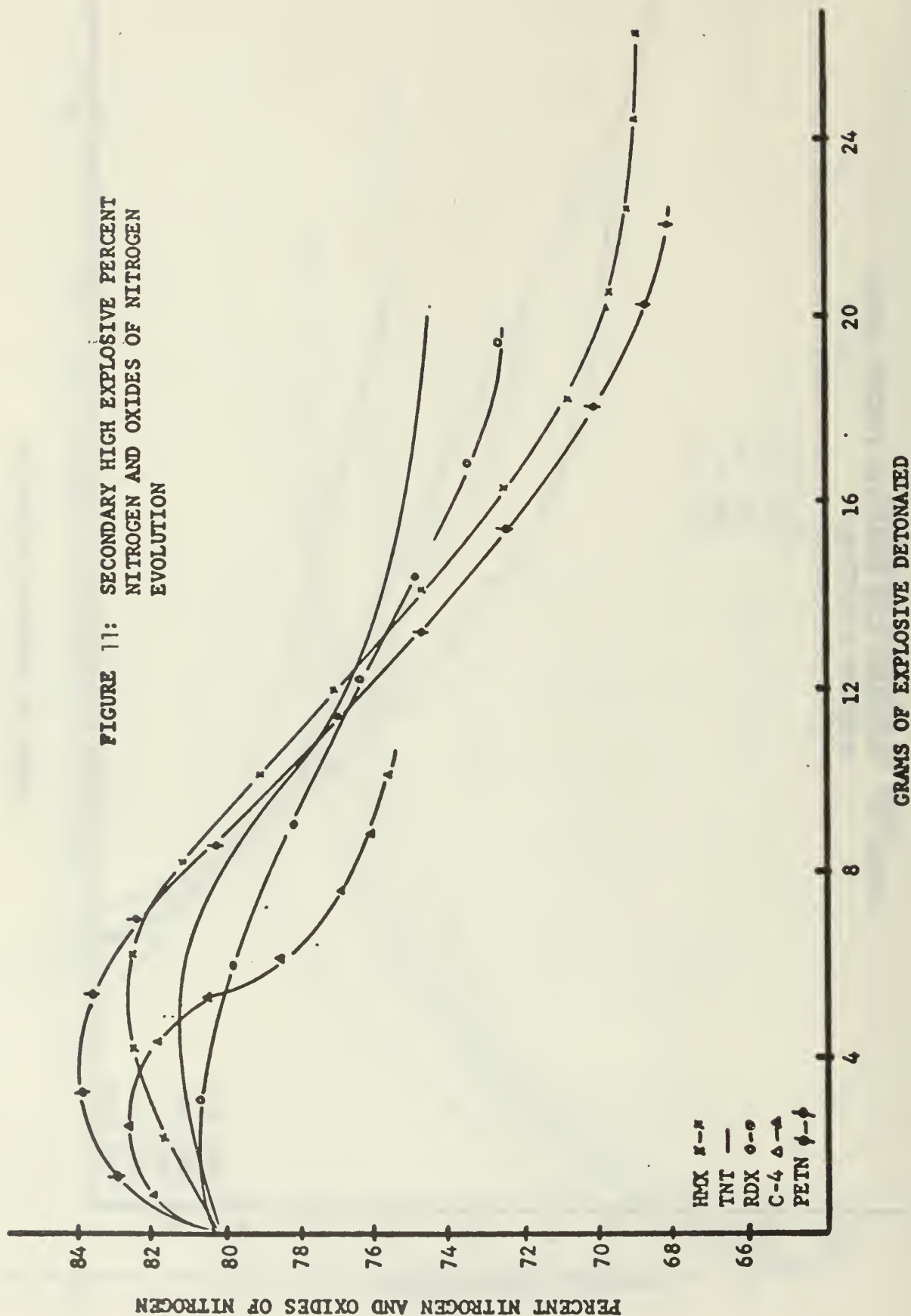


FIGURE 11: SECONDARY HIGH EXPLOSIVE PERCENT
NITROGEN AND OXIDES OF NITROGEN
EVOLUTION



Examination of the detonation chamber after each test sequence verified the expected solid carbon and aluminum residue.

To determine any long term equilibrium effects, the samples were analyzed at one day, one week, and two weeks after detonation. There were no major changes in the gas composition during a period of two weeks, due in part, to the phenomenon of "kinetic freeze-out".

The homogeneous solid propellants were then fired in a slightly modified procedure. The gaseous product concentrations exhibited much the same pattern as seen with the secondary high explosives.⁷

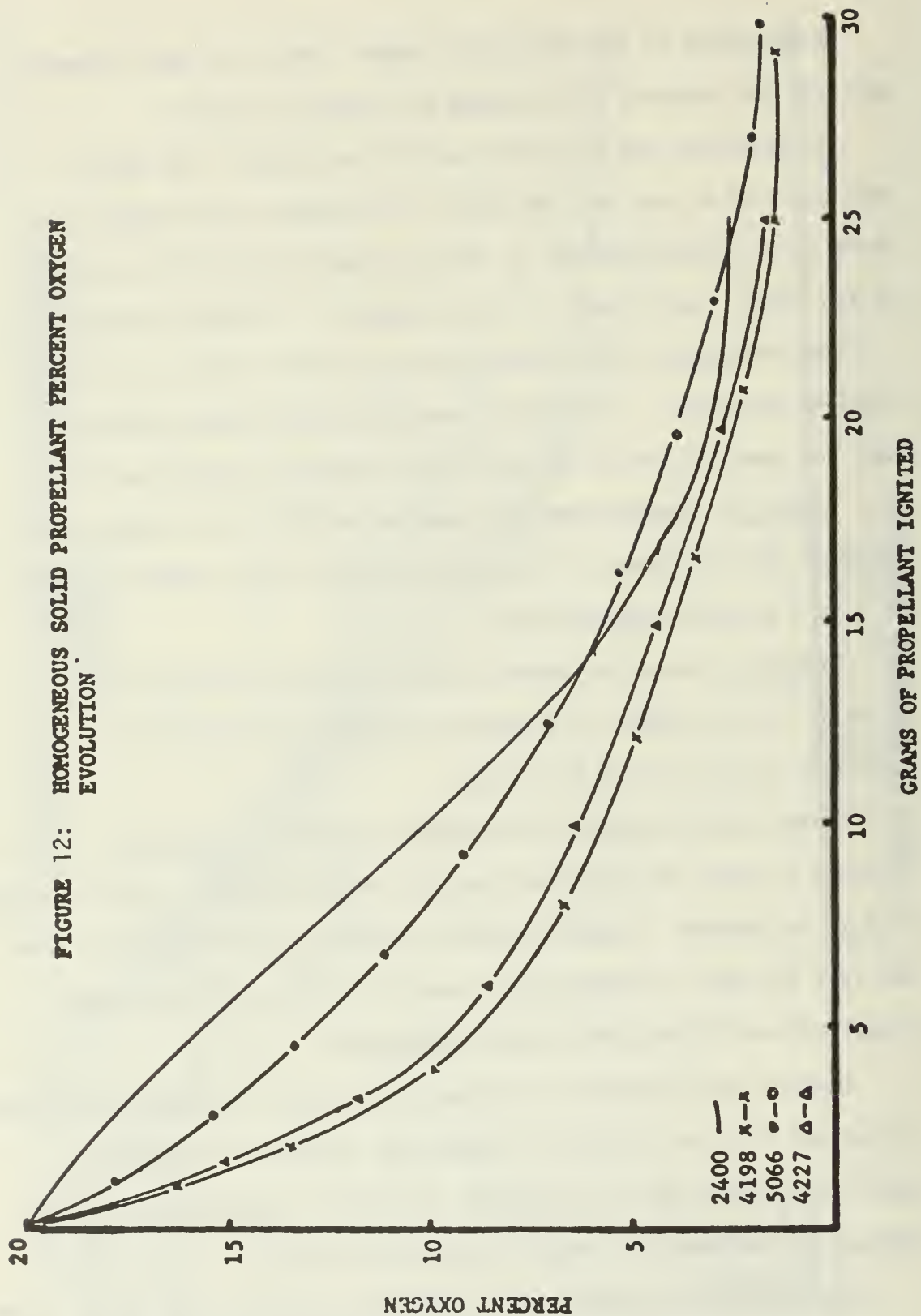
Figure 12 demonstrates the negative evolution of oxygen stabilizing at 20 to 25 grams of propellant ignited, and a stability range of 2 to 4 percent concentration.

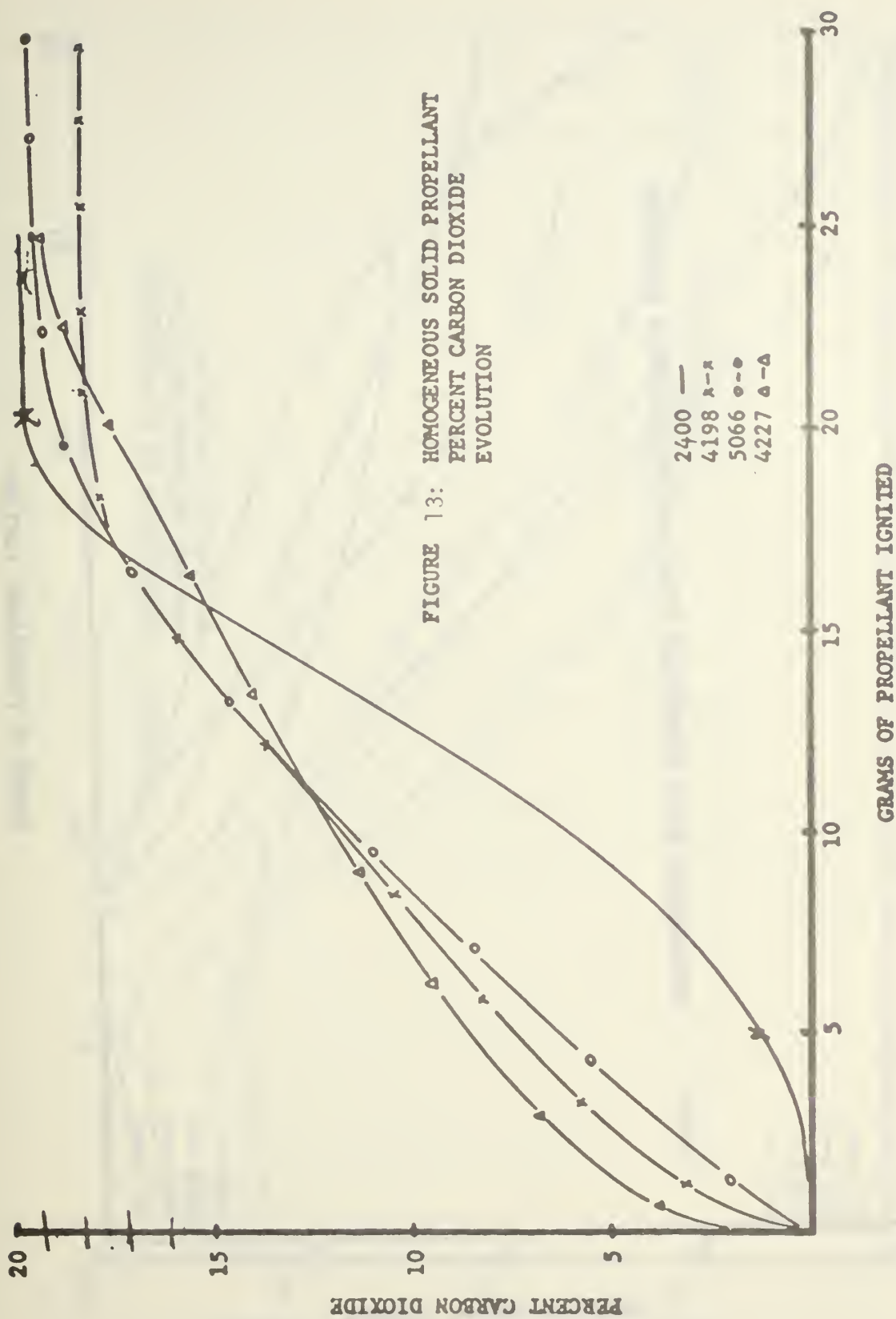
Figure 13 shows the carbon dioxide positive evolution stabilizing at 17 to 20 grams of propellant ignited and maintaining a stability range of 17 to 20 percent.

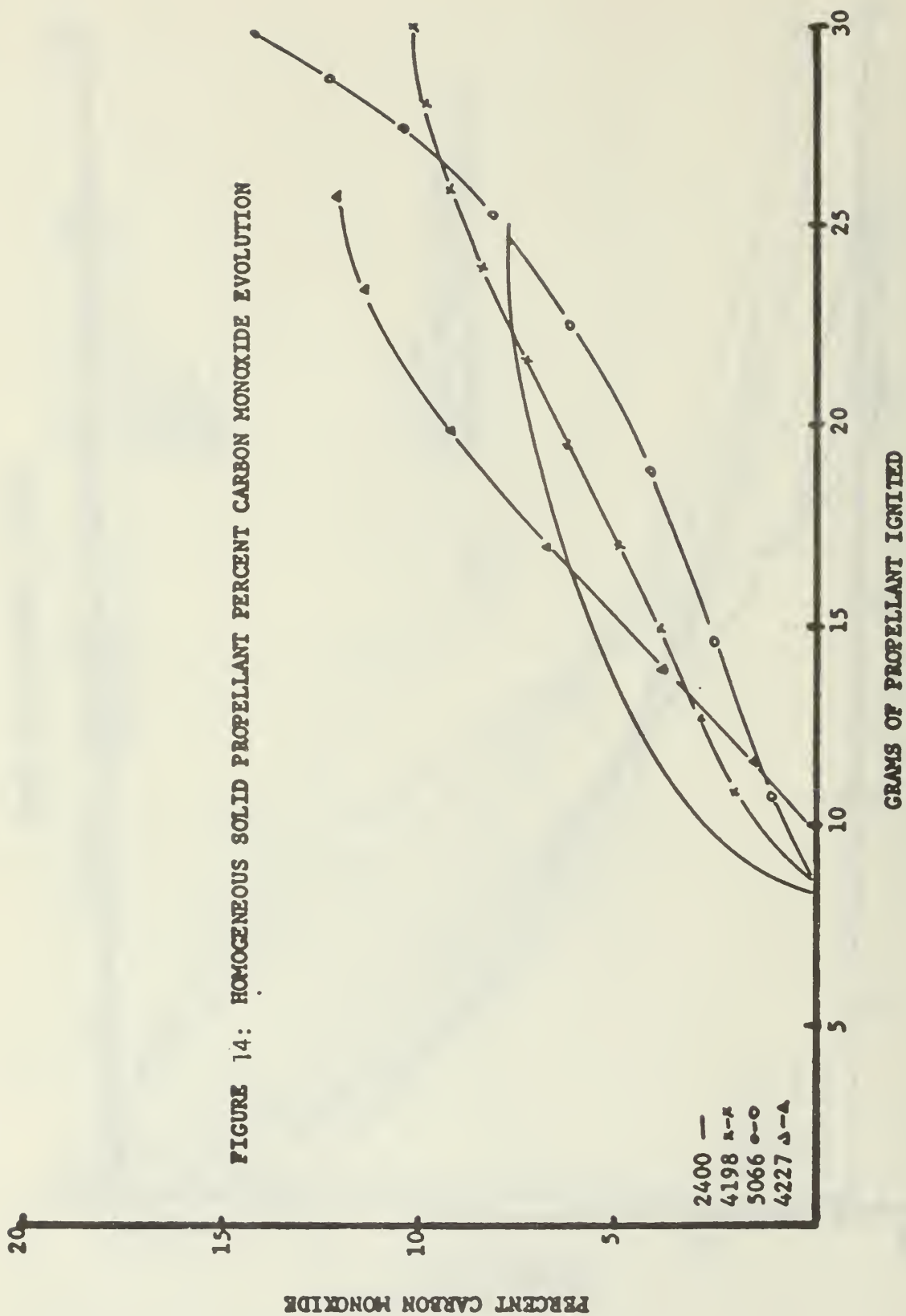
Carbon monoxide positive evolution is shown in Figure 14, stabilizing at 25 grams of propellant ignited and maintaining a stability range of 8 to 14 percent. Propellant 5066 exhibited a small deviation from the rest but this is thought to be due to its being a double based propellant while the others were single based.

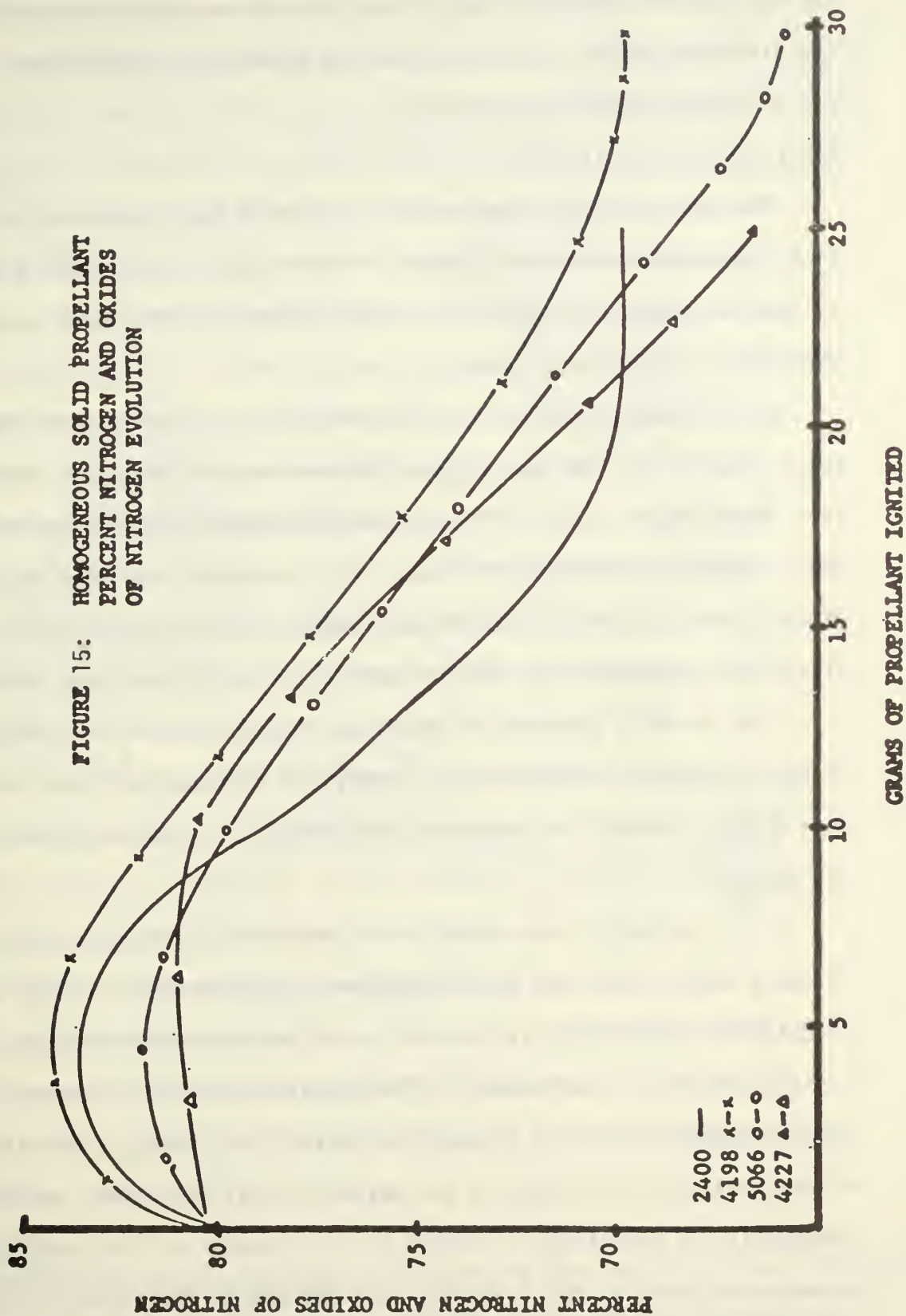
Finally, the nitrogen and oxides of nitrogen percentage concentration stabilized at 20 to 25 grams of propellant ignited and exhibited a stability range of 66 to 71 percent, as shown in Figure 15. Neither methane nor hydrogen was found during the gas analysis.

Homogeneous solid propellants exhibited the same basic trends as the secondary high explosives; differing only in the exact point of stabil-









ization and the stability range. This is to be expected in view of the different reaction mechanism (deflagration versus detonation) and different chemical composition.

Conclusions and scale-up:

The basic research done in this laboratory has shown that, at least in a laboratory scale model disposal chamber, confined chamber disposal is feasible with predictable gas concentrations and pressures, and, therefore, warrants more study.

We have shown that for both secondary high explosives and homogeneous solid propellants, the same type of gaseous product evolution is observed even though they are of different chemical compositions and operate under different reaction mechanisms. This indicates that the disposal of explosives by the confined chamber method is applicable to both classes of explosives and that the method is, therefore, simplified.

From the data gathered in these experiments and from existing data on blast and shock effects in air,^{10, 4} rock, and salt media,^{5, 11} it was felt that a basic feasibility study for a scaled-up site was warranted.

The Cavity:

If a relatively large explosion is detonated underground while in intimate contact with the surrounding medium, the medium near the point of detonation will react inelastically and be permanently deformed. Also, a strong seismic signal capable of being detected at long range will be generated and transmitted through the earth. The inelastic behavior of the medium, the strength of the seismic signal generated, and the probability of detecting the signal are all reduced as the coupling between the point of the detonation and the medium diminishes. This reduction in coupling is known as "decoupling".

Maximum decoupling can be achieved if the explosive can be detonated while at the center of a spherical underground cavity and at a distance from the cavity walls such that all walls respond elastically to the explosion-produced shock waves.¹²

An underground chamber large enough to completely decouple up to a 2.5 kT * chemical explosive shot and contain all the resultant product gases without serious static overpressures can be constructed in massive, dome-type salt formations provided (1) the salt deposit is reasonably homogeneous and free from faults, fractures, or weak seams, and (2) the in situ stresses are approximately hydrostatic.¹²

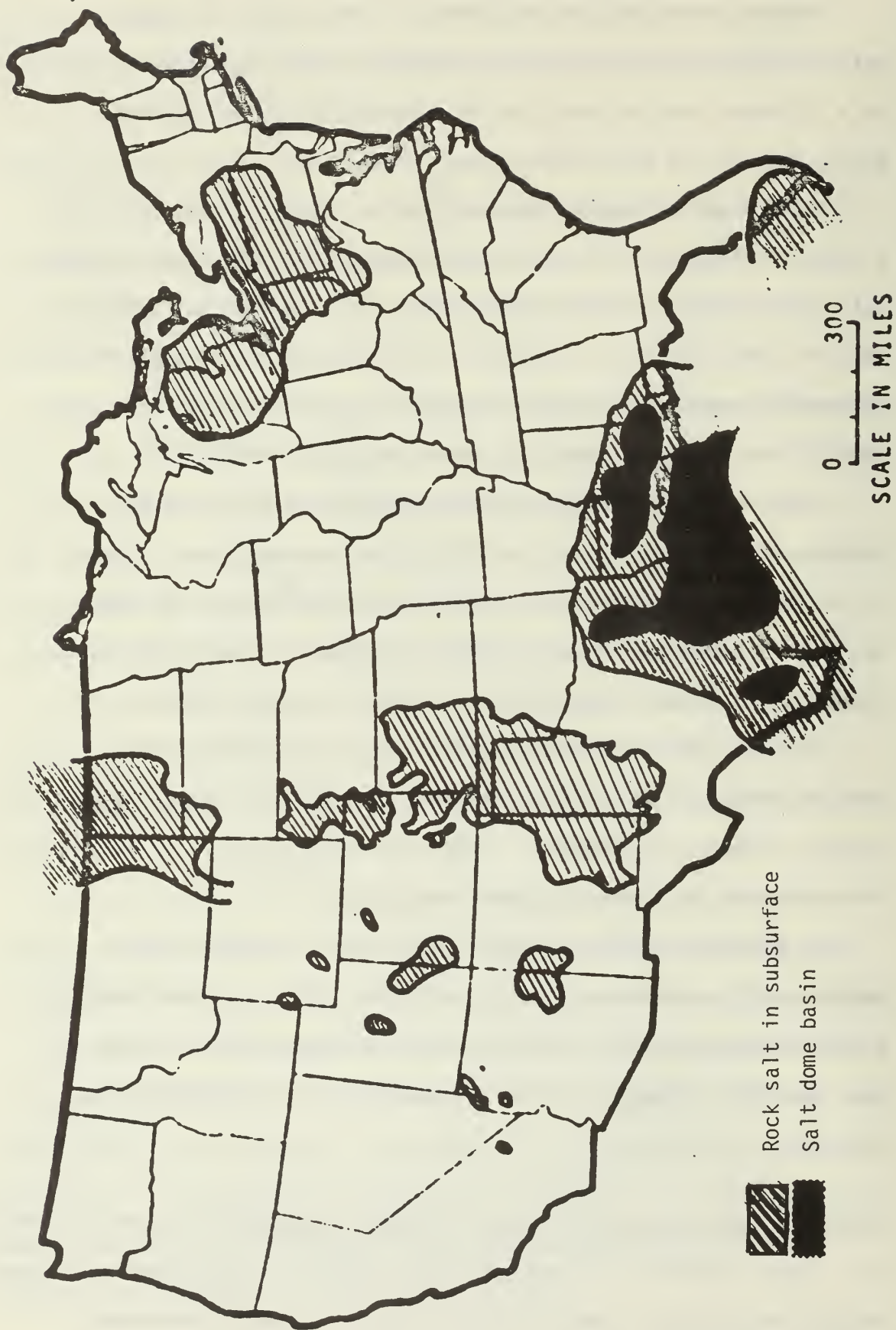
Based on an engineering report to the AEC by Fenix and Scisson Company, it seems possible to construct such an underground chamber in one of the many salt domes around the country.¹² Figure 16 shows the primary locations of usable salt formations in the United States, these cover an area of more than a half-million square miles.

Salt was chosen because it deforms quasi-plastically under pressure which allows it to absorb the high stress of cavity opening as well as being self-healing. Under compressive stress, it is impervious to the passage of gases and liquids.^{12,11}

In addition, the technology needed to mine the salt exists, one may apply conventional mining techniques (at considerable cost), or one may apply current solution mining techniques, at a savings of more than 50%. Figure 17 shows a schematic of a solution mining procedure.

*Chemical explosions operate with a different mechanism than nuclear explosion - i.e. longer duration. In general, blast data for nuclear explosions must be multiplied by two if used to predict data for chemical explosions.

Figure 16: Map of Major U. S. Subsurface Salt Deposits



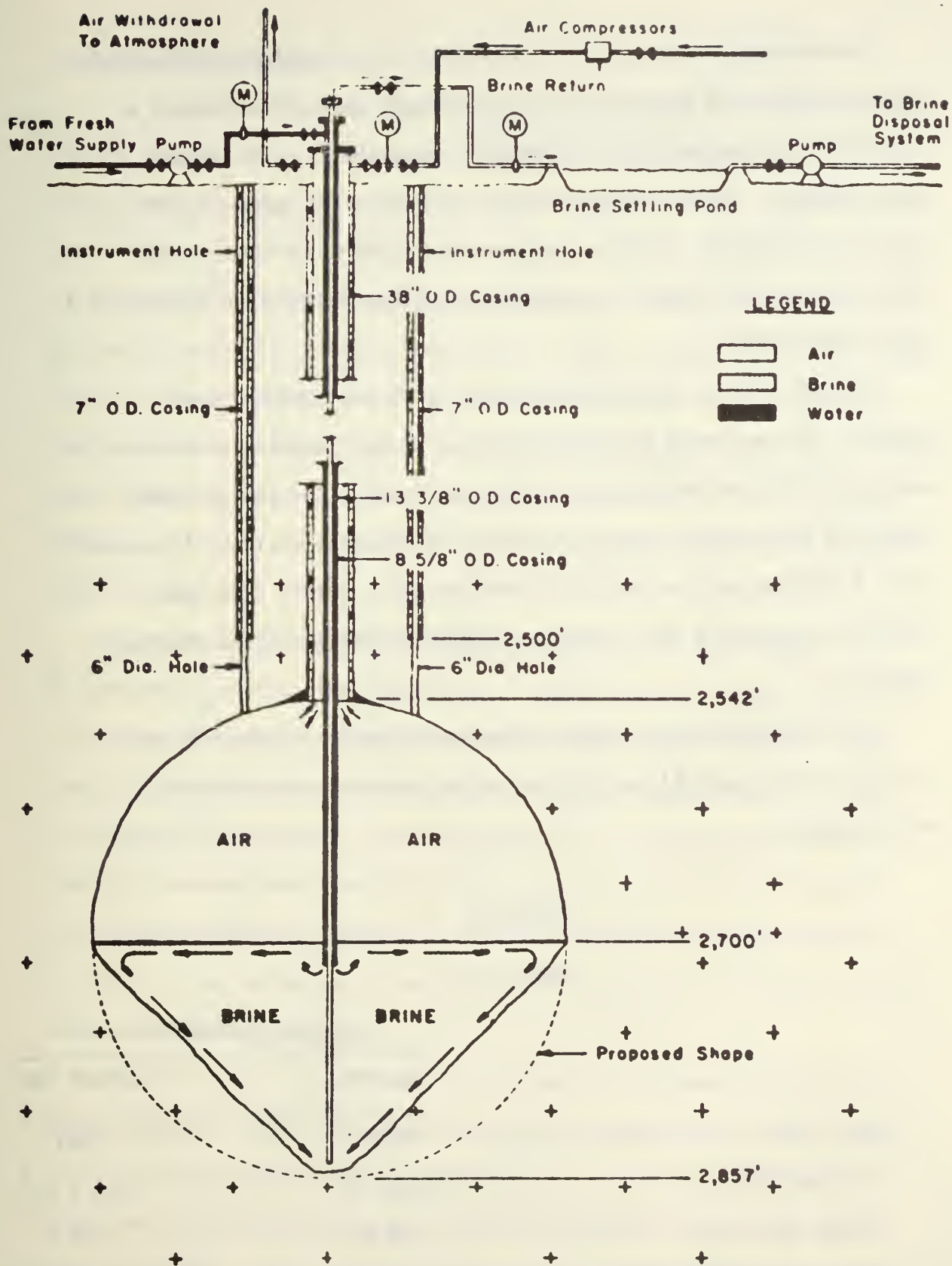


Figure 17

SCHEMATIC FOR THE SOLUTION MINING OF A 315' DIA. SPHERE

In solution mining, salt is dissolved by controlled circulation of fresh water and subsequent removal of saturated brine through a drilled hole equipped with a concentric arrangement of different sized casings. Modern solution mining can actually shape-control by using a moveable blanket of air or inert liquid to control the fluid level in the cavity. Insolubles would be removed by jetting during development.

Solution mining is safer and easier to do than conventional mining. It also would provide a means of prompt reversal of ground support should the walls start to give way within the cavity. Note that this method, while the less costly of the two, would still cost about 9,000,000 dollars for a 315 foot diameter sphere 2700 feet below the surface of the earth (to contain a 2500 ton yield chemical explosion).¹²

An alternative to the expenditure mentioned, would be the use of existing AEC test sites constructed in the 50's and 60's in halite media.

FIGURE 18

SCALE - UP

	CHEMICAL EXPLOSIVE	
	25 TON	2500 TON
DEPTH (FT)	2700	2700
VOLUME (FT ³)	1.63 x 10 ⁵	1.63 x 10 ⁷
RADIUS (FT)	33.9	157.5
COST - CONVENTIONAL (\$)	-	19,000,000
COST - SOLUTION (\$)	-	8,900,000

Mechanism of disposal:

As stated before, the quantities of explosives available for disposal are not small. They are located throughout the country, mostly at ammunition depots. Figure 19 shows the major Navy ammunition depots in the United States. Notice that most of these are not particularly near any of the usable salt formations shown previously. This means that to get to the disposal site, long transportation times and distances are encountered. This is perhaps one of the big disadvantages to this proposed system. However, in looking at other disposal systems under consideration now, it seems likely that these explosives will have to be transported anyway. It is only a question of the distances and costs of transportation involved.

Once at the transportation site, the explosives would again have to be handled in off-loading, stored for a time, and then loaded by some as yet unspecified means down into the hole. Some suggestions have been that the explosives be encased in foam while being sent down the tube, or attached to a conveyor type arrangement. The access shaft cannot feasibly be made more than 72" cased diameter, which limits the size of the cased explosives somewhat. Notice that I said cased explosives, for this is one advantage of this system -- the explosive devices may be emplaced without uncasing.

However, once in the chamber, the operation becomes a significant safety hazard. These units must be placed at the center of the sphere and within sympathetic detonation distances, most likely by human operators. Also, some method of placing detonators around the huge mass is needed. These operations are inherently dangerous, although the safety aspects may be overcome at some later time.

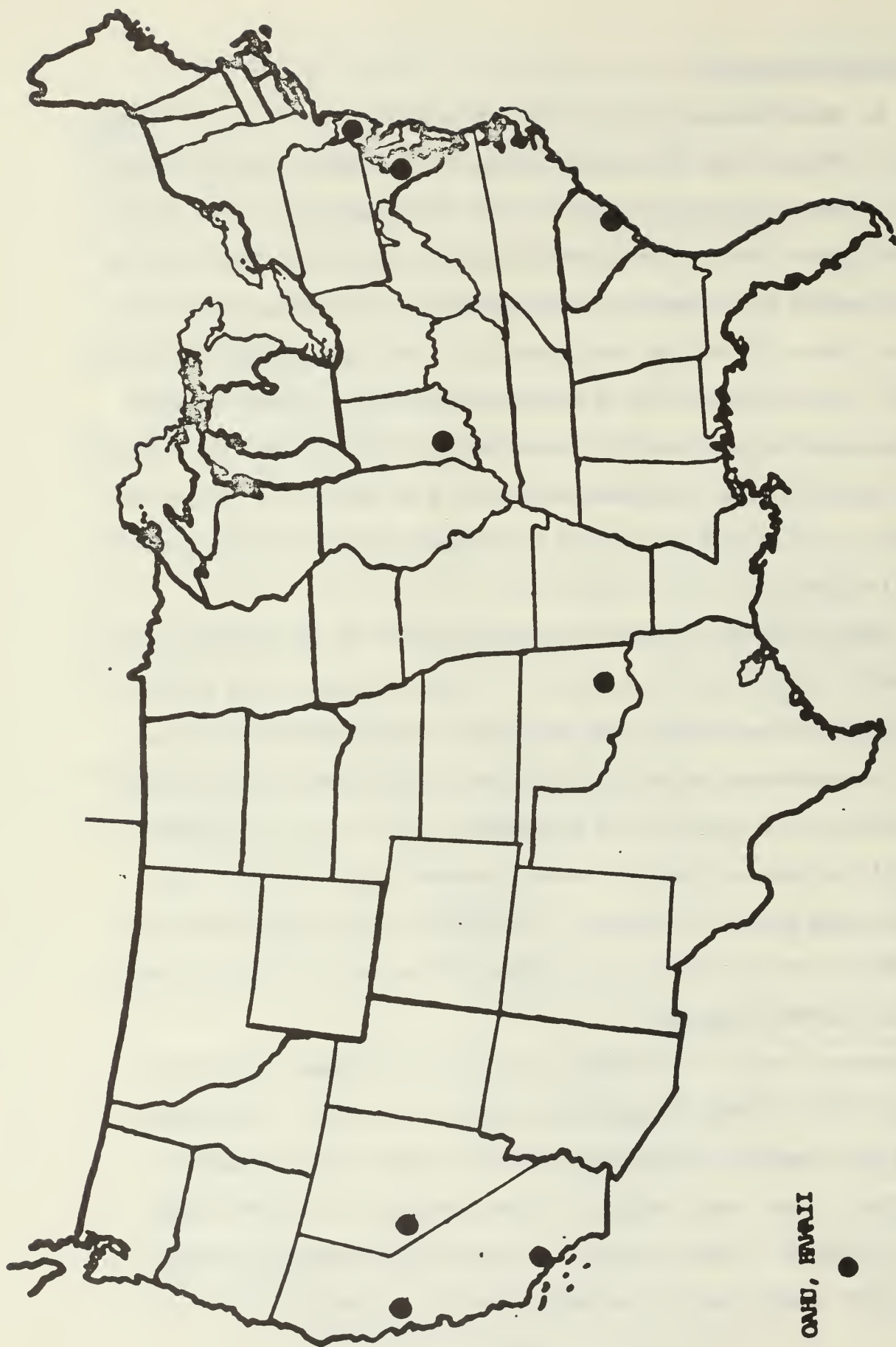


Figure 19. Nava1 Establishments storing excess explosives

After loading, a concrete wedge would be placed in the access shaft and the high explosive and propellant mass would be remotely fired, producing copious quantities of gases, variously sized particles and pieces of metal, and solid carbon in the form of graphite, but which would be totally contained within the sphere.

Gas overpressures at the end of the shot would not be tremendous. Indeed, in the 25 ton shot site mentioned earlier, final overpressures would be in the range of 4 atmospheres (60 psi). Peak detonation pressures during the blast would be about 92.4 atm (1358 psi) at the wall of the sphere with short duration.¹³ Note that this is considerably less than the overburden pressure at depth which amounts to about 800 bars (11,760 psi) which simply means that the hole would not blow out or get significantly larger.¹²

Pollution Standards:

The reason for this project in the first place was to try to eliminate the pollution problems associated with explosives disposal. There are really only three chemical products of any environmental concern. These are the (1) oxides of nitrogen, (2) carbon monoxide, and (3) particulates, such as carbon (soot), and the notorious metal oxide dusts.

NO_x standards are taken to be those of a nitric acid plant, since this is a stationary source of "nitric acid". The applicable standard sets the limit on emissions as about 220 ppm measured as NO₂.¹⁴ I have not found an applicable standard for carbon monoxide other than the federal ambient air quality standard of 9 ppm (10 mg/m³) for 8 hours maximum, or 35 ppm (40 mg/m³) one hour, max, once per year, which is

probably very much too low for a stationary source.¹⁵ Particulate standards for soot and metal oxide particles are set at 180 mg/m^3 ¹⁶ max, (two hour average) which for carbon works out to be 368 ppm. In all cases, dilution or processing would be needed.

Product recovery:

Product recovery at this point in the study does not look entirely feasible. If one were trying to recover NO_2 to form nitric acid, to pay for the facility or to use in further synthetic work, 50 tons of TNT would give only 4.2 tons of nitric acid (100% basis) maximizing the yield of NO_x at 10% (which is certainly high)*. At the going market prices, this amounts to 453 dollars, which would hardly pay the transportation costs for one truck load of ordnance, and certainly would not warrant building a \$100,000 - 250,000 product reclamation plant.

However, 50 tons of TNT would yield about 36 tons of CO , which conceivably could be used for fuel in a turbine-type electric generator.

Perhaps the most useful products of the explosion would be the metals left in the shot cavity. If enough shots were fired, it would be a very rich source of metal ores that might be economically feasible to mine.

Conclusions:

Disposal in a confined space at this time in the study, seems advantageous when one wishes to dispose of large batch quantities of explosive devices which are perhaps dangerous to uncase, where another method does not exist, and from the standpoint of environmental impact. The method

* Reference 1 suggests a 7.5% NO_x from open burning of TNT.

seems to be at a disadvantage when other methods of disposal exist, such as wet-air oxidation or controlled incineration, when the munitions may be easily and safely uncased, or when continuous operations are feasible.

Primary disadvantages are in transporting the old, perhaps sensitive devices, over long distances, the large initial investment required, and the dangers of emplacement.

Lastly, in general, reclamation of the gaseous products does not look practical at this time.

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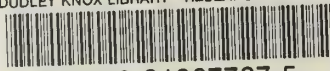
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